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RESPONSE OF *SYNGONIUM PODOPHYLLUM* TO NANO AND CHEMICAL FERTILIZERS IN A SUSTAINABLE AQUAPONIC FARMING SYSTEM

Jihan Y. Al-Hatem

Department of Horticulture and Landscape, College of Agriculture and Forestry, University of Mosul, Mosul, Iraq

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Correspondence Email:
jahan.yahya@uomosul.edu.iq

ABSTRACT

Amid efforts to integrate advanced technologies into agriculture, aquaponics has emerged as an integrated solution for developing sustainable agricultural systems. It combines aquaculture and soil-less culture, providing an ideal environment for plant growth. Based on this, research was conducted to propagate *Syngonium podophyllum* using this technology, while also studying the effect of synthetic nano-NPK fertilizer and comparing it with conventional NPK fertilizer on the growth and propagation of this plant. The experimental data conclusively demonstrated that foliar application of nano-NPK fertilizer at 1 and 2 mg L^{-1} concentrations enhanced key plant grow parameters ($p<0.05$), contributed to stimulating plant growth, particularly plant height and stem diameter. It also noted an increase in the length of the longest root. Furthermore, the concentrations of nitrogen and potassium in treated plants significantly increased compared to conventional fertilizers, both of which outperformed the control treatment. Chlorophyll and carotene concentrations also increased, reaching 22.664 and 102.86 mg L-^{1}, respectively, when fertilized with nano-NPK fertilizer at a concentration of 1 mg L-^{1}. This is due to the unique properties of nano-fertilizers, such as increased absorption, slow release of nutrients, and other advantages. These results open new horizons for enhancing the efficiency of aquaponic systems through nanotechnology applications, contributing to higher productivity and better quality of plant crops, supporting the development of modern agriculture in Iraq.

College of Agriculture and Forestry, University of Mosul.

INTRODUCTION

The Syngonium plant, *Syngonium podophyllum,* belongs to the Araceae family and is native to the tropical rainforests of Central and South America. It has attractive, glossy, smooth leaves that change shape as the plant grows, starting as lanceolate and becoming divided with age (Zhou *et al*., 2023). Its color ranges from dark green to light green, with white or yellow spots in some cultivars. Its adaptability. Its long stems make it suitable for planting as a ground cover in shaded areas or as a hanging hedge (Kasem and Helaly, 2021). Irga *et al*. (2013) reported that *S. podophyllum* grown in a hydroponic system exhibits high efficiency in removing carbon dioxide (CO_2) from the air compared to soil-based cultivation. Therefore, hydroponically grown plants demonstrate considerable potential for improving indoor air quality, especially when integrated with modern cultivation technologies. This plant is an excellent choice for urban green spaces owing to its shade tolerance and air-purifying ability (Al-Hatem and AL-Taee, 2025).

The Nutrient Film Technique (NFT) aquaponics system is an innovative and sustainable solution for propagating ornamental plants. It combines aquaculture (fish) and hydroponics as a closed, sustainable, symbiotic agricultural system (Aslanidou *et al*., 2023). Aquaponics contributes to sustainable agriculture by reusing aquaculture wastewater as a natural fertilizer, thus reducing water waste, as fish waste is used as a natural fertilizer for plants, providing a sustainable and efficient environment for plant propagation (Lauguico *et al*., 2024). This makes it an ideal choice for urban and home agriculture (Salman and Abdul Rasool, 2022). Rajalakshmi and Gunasekaran (2024) reported that nutrient uptake efficiency in hydroponic systems can be enhanced by utilizing plant species capable of removing nitrates from contaminated water. Their finding revealed that plants, such as S. *podophyllum,* effectively purified water and supported plant development, making them a promising choice for sustainable agriculture and water reclamation. According to Kaleel and Ali (2024), significant improvements in water efficiency and yield can be achieved through these systems. This performance depends on a dynamic balance of water flow rates according to precise hydraulic equations. However, this system faces challenges in terms of poor nutrient balance and low nutrient absorption efficiency (Le *et al*., 2024).

Aquaponics is witnessing remarkable development, especially with the development of nanotechnology. Nanofertilizers are a powerful addition to the success of aquaponics, providing innovative solutions to address the challenges of sustainable agricultural production. Nanofertilizers are plant nutrient fertilizers processed using nanotechnology, made of very small particles (less than 100 nanometers) (Al-Juheishy and Ghazal, 2023), making them up to 40% faster to absorb than traditional mineral fertilizers. They can complement the natural diet of plants while maintaining the delicate ecological balance of the system, enhancing the efficiency of aquaponics systems. One of the main challenges in aquaponics is maintaining an ideal nutrient concentration, provided that it does not harm fish while meeting the needs of plants. Nanofertilizers designed with phased release can solve this problem, as they release nutrients slowly and sustainably, such as nitrogen, phosphorus, and potassium (Abobatta, 2023). Although nanofertilizers can enhance nutrient delivery in aquaponic systems, they must be used with caution to avoid disturbing the delicate balance between plants, fish, and microbes (Ibrahim *et al.*, 2025). Mohammed *et al*. (2023) showed that plant growth is 20–30% faster due to the continuous availability of nutrients. Fertilizing with NPK nano fertilizer, this is confirmed (Atallah and Hassan, 2022).

The research aims to propagate *S. podophyllum* using a hydroponic system, and to study the effect of nano-fertilizers and compare them with traditional mineral fertilizers to ensure successful propagation with high quality. We hope this technology will become widely available, especially in urban areas and resource-limited environments. This will support sustainable development goals in terms of high productivity and improved quality, and reduce the costs and environmental impacts of agriculture, especially in Iraq.

MATERIALS AND METHODS

The study was conducted using locally manufactured aquaponic units to study the effect of two types of NPK fertilizers (nano and conventional mineral) on the growth and propagation of *S. podophyllum* from August 1, 2024 to February 25, 2025. After preparing the units and filling them with clean DE chlorinated water, nitrogen-fixing bacteria were activated on September 1, 2024. *Cyprinus rubrofuscus* fish and *S. podophyllum* seedlings were added after one month of water recycling. Nano-NPK (2-1-3) fertilizer and conventional mineral-NPK (2-1-3) fertilizer were used as foliar sprays. The experiment was conducted using a Complete Randomized Design (CRD) with three replicates and five plants per replicate. The data were analyzed using SAS (2005) software, and Duncan's multiple range test was adopted at the 5% level according to Hoshmand (2017). The vegetative group of plants was sprayed three times throughout the experiment. The hydroponic units were divided according to the type of fertilizer used as follows:

1. Hydroponic units (control): The plants were sprayed with distilled water.
2. Hydroponic units fertilized their plants with nano-NPK (2-1-3) fertilizer at a concentration of 1 mg L^{-1}.
3. Hydroponic units fertilized their plants with nano-NPK (2-1-3) fertilizer at a concentration of 2 mg L^{-1}.
4. Hydroponic units fertilized their plants with conventional NPK (2-1-3) fertilizer at a concentration of 1 g L^{-1}.
5. Hydroponic units fertilized their plants with conventional NPK (2-1-3) fertilizer at a concentration of 2 g L^{-1}.

The units were designed using a closed-loop (NFT) system inside a greenhouse belonging to a private nursery. Each unit consists of an iron stand (200) cm long and (100) cm wide, divided into three shelves connected via plastic tubes through which water circulates. Each shelf contains the following:

1. The upper shelf: Contains the hydroponic units using the Nutrient Film Technology (NFT): Each unit contains three plastic tubes, 70 cm long and (2) inches in diameter. Each tube has five holes (7.5) cm in diameter, with two (7) cm diameter perforated anvils for placing *S. podophyllum* seedlings.
2. The middle shelf: Contains a glass tank measuring (70 x 40 x 70) cm^3 for fish farming.
3. Lower shelf**:** Contains the (Filter Unit), a glass aquarium (70 x 40 x 70 cm) divided into three non-connected sections at the bottom. Water laden with solid and liquid fish waste is transferred to it for purification and recycling. It consists of: (a) A mechanical filter to purify the water from solid waste using a polyethylene mesh. (b) A bio-filter containing Bio-Balls plastic pellets to support the activity of beneficial bacteria (nitrifying bacteria) that convert ammonia to nitrite and then nitrate. (c) A pump that recirculates clean water to the plant growing units. The system also includes an air compressor to provide oxygen, a heater to maintain the water temperature in winter, and LED lighting to support plant growth. S. podophyllum cuttings were prepared from a reliable nursery in Nineveh Governorate, rooted in water for two and a half months, then transferred to hydroponic anvils using expanded clay as substrate on 1-10-2024, and placed in NFT units within the aquaponic system. Water was recycled at a rate of (1-2) liters/minute. The pH was adjusted to 6-6.5. Nitrogen (Lauguico *et al*., 2024), nitrite, and nitrate concentrations were evaluated in the central laboratory of the College of Agriculture and Forestry/University of Mosul.

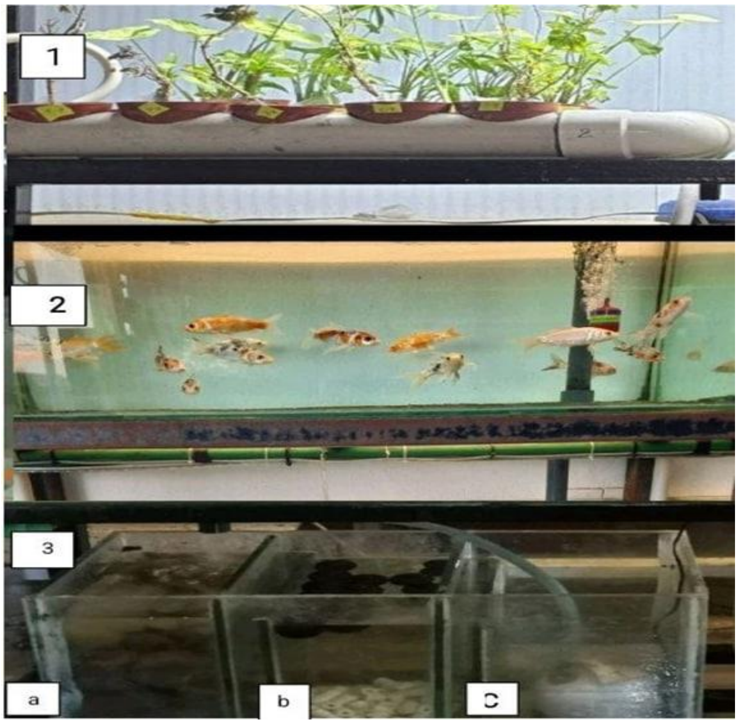

Figure (1): Components of an aquaponic system: (1) Plant culture tubes, (2) Fish culture tanks, (3) Mechanical and biological filter tanks, (a) Mechanical filter, (b) Bio filter, and (c) Water sublimation pump

Traits studied

- Vegetative growth traits: Data for these traits were recorded at the end of the experiment (approximately four months later), and the following experimental traits were measured:
- Plant height (cm): Measured using a measuring tape from the soil surface to the tip of the plant.
- Basal internode diameter (mm)**:** Calculated using a caliper.
- Leaf chlorophyll and carotene concentrations (mg/100g fresh weight): Estimated using an Apel PD-303 UV spectrophotometer at wavelengths of 663, 645, and 447 nm, according to the method of (Anonymous,2020).
- Estimation of total soluble sugars (%)**:** Absorbance was measured at a wavelength of 560 nm using a spectrophotometer according to the method of Bader et al. (2024).
- Estimation of leaf nutrients (%): Dry and ground samples were digested according to (Temminghoff and Houba, 2004).
- Total nitrogen concentration (%): Using a microkjeldahl nitrogen meter, as described by (Sáez-Plaza *et al*., 2013).
- Total phosphorus concentration (%): Using a spectrophotometer at a wavelength of 420 nm, according to (Temminghoff and Houba, 2004).
- Total potassium concentration (%): Using a flame photometer, according to (Temminghoff and Houba, 2004).
- Concentration of trace elements, iron and zinc, in plants (%): Using an atomic absorption spectrophotometer, according to (Sáez-Plaza *et al*., 2013).

RESULTS AND DISCUSSION

Table (1) shows the concentrations of ammonia, nitrite, and nitrate in the water of the aquaculture units. The lowest concentration was in the water of the plant growth units and the control treatment, reaching 0.008 parts per million. The highest nitrite concentration was observed in the water of the biological filter tanks of the control treatment, reaching 0.57 parts per million. The highest nitrate concentration was also observed in the water of the biological filter tanks and plant growth units, especially the treatment fertilized with 1 g/L^{-1} nano-NPK fertilizer, reaching 14.11 and 14.05 parts per million, respectively.

Table (1): Concentration of ammonia, nitrate and nitrite (ppm) in the water of both fish tanks, biological filter tanks and *S. podophyllum* plant growth units for both control treatment plant units and units whose plants were fertilized with 1g L^{-1} nano NPK fertilizer

Transactions	Ammonia concentration ppm	Concentration NO_2 ppm	Concentration NO_3 ppm
Fish tank water connected to NFT pipes, control treatment plants	0.040	0.10	13.24
Biofilter tank water connected to NFT pipes, control treatment plants	0.019	0.57	13.50
NFT plant growth unit water (control treatment plants)	0.008	0.021	13.40
Fish tank water connected to NFT pipes, their plants fertilized with 1 mg L^{-1} nano-NPK fertilizer	0.066	0.17	12.68
Bio-filter tank water connected to NFT pipes, their plants fertilized with 1 mg L^{-1} nano-NPK fertilizer	0.0214	0.51	14.11
NFT plant growth unit water fertilized with 1 mg L^{-1} nano-NPK fertilizer	0.021	0.056	14.05

The low ammonia concentration (0.008 ppm) in the water of the control-treated plant growth units (NFTs) indicates a high efficiency in plant uptake of nitrogen compounds. Plants prefer direct ammonia uptake (NH_4^+) because it requires less energy compared to nitrate conversion (NO_3^-), which reduces its concentration in the water (Roosta *et al*., 2025). The high nitrate concentration (14.05 ppm) in the plant units treated with nano-NPK may be due to increased nutrient availability due to the nanoparticle size, which enhances nitrogen availability to plants (AL-Malikshah and Abdulrasool, 2024). The ammonia concentration in the aquaponics units is within the optimal levels for fish farming. Bio-filters produce higher nitrates due to microbial activity. The high nitrate concentration in bio-filters reflects the activity of nitrifying bacteria Nitrobacter and Nitrosomonas, which convert ammonia to nitrite and then to nitrate in a process called nitrification. Nano fertilization may have stimulated the activity of nitrogen-degrading microbes in the roots (Lauguico *et al*., 2024).

The results of Table (2) show that the highest significant value for the trait plant height was when fertilized with 1 and 2 mg L^{-1} nano NPK fertilizer, which reached (26.2 and 26.9) cm, respectively, compared to the lowest significant value for the control treatment, which was 19.1 cm, while the best significant value for the trait basal intermodal diameter was when fertilized with 2 mg L^{-1} nano NPK fertilizer, which reached 10.3 mm. The best significant value for the trait fresh weight of the vegetative system was when fertilized with 1 mg L^{-1} nano NPK fertilizer and the traditional mineral fertilizer at a concentration of 1 g L^{-1}. All fertilization treatments (with any fertilizer studied and at any concentration) were significantly superior for the trait length of the longest root and the trait wet weight of the root system, compared to the lowest significant values for the control treatments.

Table (2): The effect of nano-NPK fertilizer and conventional mineral NPK on some vegetative growth traits in *S. podophyllum* plants within the aquaponics system.

Treatments	Plant height (cm)	Basal internode diameter (mm)	Leaf wet weight (g)	Length of longest root (cm)	Root wet weight (g)
Control treatment plants	19.1 c	6.9 c	9.11 c	9.2 c	4.4 b
Plants fertilized with 1 mg L^{-1} nano-NPK fertilizer	26.2 a	18 b.8	13.4 a	16.2 a	6.5 a
Plants fertilized with 2 mg L^{-1} nano-NPK fertilizer	26.9 a	10.3 a	12.5 ab	15.1 a	6.7 a
Plants fertilized with 1 g L^{-1} NPK fertilizer	21.2 b	8.5 b	13.2 a	15.3 a	6.8 a
Plants fertilized with 2 g L^{-1} NPK fertilizer	23.3 b	7.8 b	10.9 bc	12.5 b	6.2 a

Values with the same letters for each factor individually in the same column are not significantly different according to Duncan's multiple range test at the 5% probability level.

The results of Table (3) show that the best significant value for the concentration of both total chlorophyll and beta-carotene pigments was obtained when fertilizing with 1 mg L^{-1} nano NPK fertilizer, and it reached (22.66 and 102.86) mg g^{-1} wet weight, respectively, compared to the lowest significant values for the control treatments. On the other hand, it was noted that the best significant values for the carbohydrate concentration trait were all superior to the control treatment.

The results of Table (4) show that the highest significant value for nitrogen concentration was obtained when fertilizing with 1 and 2 mg L^{-1} nano NPK fertilizer, as well as when fertilizing with 1 g L^{-1} NPK fertilizer, reaching (2.74, 2.45, and 2.46) %, respectively, compared to the lowest significant values for the control treatment, which reached 0.96%.

Table (3): The effect of nano-NPK fertilizer and conventional mineral NPK on the percentage and concentration of chlorophyll, carotene, and total soluble sugars in *S. podophyllum* plants within the aquaponics system

Treatments	Chlorophyll (mg g^{-1}) wet weight	Beta-carotene (mg^{-1}) wet weight	total soluble sugars (%)
Control treatment plants	12.901 c	76.09 c	8.95 b
Plants fertilized with 1 mg L^{-1} nano-NPK fertilizer	22.664 a	102.86 a	10.90 a
Plants fertilized with 2 mg L^{-1} nano-NPK fertilizer	17.873 b	86.03 b	10.23 a
Plants fertilized with 1 g L^{-1} NPK fertilizer	18.432 b	82.78 b	10.56 a
Plants fertilized with 2 g L^{-1} NPK fertilizer	16.294 b	84.80 b	9.69 ab

Values with the same letters for each factor individually in the same column are not significantly different according to Duncan's multiple range test at the 5% probability level.

However, no significant differences were observed in the effect of nano fertilizers on the percentage of phosphorus in plants. The highest significant values for potassium concentration were when fertilizing with 1 mg L^{-1} nano NPK fertilizer, which reached 0.75%, compared to the lowest significant values for the control treatment and when fertilizing plants with 2 g L^{-1} NPK fertilizer, which reached (0.55 and 0.49) %, respectively.

Table (4): The effect of nano-NPK fertilizer and conventional mineral NPK on the percentage of some major nutrients for *S. podophyllum* plants in an aquaponics system.

Treatments	N %	P %	K %
Control treatment plants	0.96 c	0.157 a	0.55 c
Plants fertilized with 1 mg L^{-1} nano-NPK fertilizer	2.74 a	0.135 a	0.75 a
Plants fertilized with 2 mg L^{-1} nano-NPK fertilizer	2.45 a	0.172 a	0.68 b
Plants fertilized with 1 g L^{-1} NPK fertilizer	2.46 a	0.157 a	0.66 b
Plants fertilized with 2 g L^{-1} NPK fertilizer	1.27 b	0.140 a	0.49 c

Values with the same letters for each factor individually in the same column are not significantly different according to Duncan's multiple range test at the 5% probability level.

Table (5) shows that the best significant value for iron concentration in *S. podophyllum* was for iron concentration when fertilized with 1 mg L^{-1} NPK fertilizer, and there were no significant differences between the rest of the treatments. In contrast, no significant differences were observed in the concentration of zinc and copper elements. The best significant value for magnesium concentration in plants was when fertilized with plant fertilizer fertilized with 1 and 2 mg L^{-1} nano NPK fertilizer, which reached (0.0025 and 0.0026) %, respectively.

Table (5): The effect of nano-NPK fertilizer and conventional mineral NPK on the percentage of some minor nutrients for *S. podophyllum* plants in an aquaponics system.

Treatments	Fe%	Zn%	Cu%	Mn%
Control treatment plants	0.0025 b	0.0027 a	0.0022 a	0.0008 c
Plants fertilized with 1 mg L^{-1} nano-NPK fertilizer	0.0033 b	0.0069 a	0.0019 a	0.0025 a
Plants fertilized with 2 mg L^{-1} nano-NPK fertilizer	0.0034 b	0.0038 a	0.0012 a	0.0026 a
Plants fertilized with 1 g L^{-1} NPK fertilizer	0.0071 a	0.0036 a	0.0021 a	0.0015 b
Plants fertilized with 2 g L^{-1} NPK fertilizer	0.0127 b	0.0031a	0.0022 a	0.0002 c

Values with the same letters for each factor individually in the same column are not significantly different according to Duncan's multiple range test at the 5% probability level.

Aquaculture water is a good source of irrigation for plants due to its high organic matter content, which can improve the quality of the irrigated plants (Lauguico *et al*., 2024). However, it is preferable to add fertilizers, especially at appropriate levels, to compensate for nutrient deficiencies within a sustainable aquaponics system (Salman and Abdulrasool, 2022).

Nanotechnology has tremendous potential to revolutionize agriculture, as well as related fields, including aquaculture. Nanofertilizers increase plant biomass (increased dry matter production of stems and roots) by increasing their nutrient content, thus improving plant growth. This is consistent with what (Al-Hatem and AL-Taee, 2025), demonstrated. This may be due to the fact that the nanoscale is very small, at (1) nanometer (equivalent to one billionth of a meter = 9^{-10} meters) (Hameed and Khalil, 2023). At this scale, the physical and chemical properties of materials are different from larger scales. These fertilizers are also characterized by slow decomposition, and the release of nutrients in a controlled manner, especially when added to the plant in small quantities. This results in an increase in the efficiency of the nutrients released from them (Hassan *et al*., 2025). Nanofertilizers play an important role in physiological and biochemical processes by increasing the availability of nutrients, which enhances metabolic processes and, consequently, promotes meristematic tissue activity, increasing apical growth and the area of photosynthetic leaves. Once nanofertilizers enter the plant, they bind to ion transporters and channels, creating new openings that facilitate water absorption and encourage plant growth. Plants suffering from nutrient deficiencies exhibit poor growth. These results are consistent with those of (Al-Juheishy and Ghazal, 2023), who demonstrated the effectiveness of nanoparticles as a result of the availability of macronutrients such as nitrogen, potassium, and phosphorus, and micronutrients such as iron, zinc, boron, and copper, which are essential for plant growth. This positive effect increases vital processes, most notably photosynthesis and other metabolic activities (Al-Zebary *et al.*, 2023). This leads to an increase in plant receptors responsible for cell division and elongation, which is preceded by a positive change in the levels of plant hormones, most notably auxins, gibberellins, and cytokinins (Al-Obady and Shaker, 2022). Nitrogen is an element that has an undeniable role in increasing leaf growth in plants that are just starting to grow. Phosphorus is an effective element in stimulating root growth, flowering, and plant performance, and potassium, an element, has a positive effect on the overall performance of the plant, as supported by (Kadhim *et al*. 2022). The increase in plant quality may be due to the enhancement of physiological processes, such as increasing the plant's chlorophyll content, antioxidant activity and increased growth hormones, and the application of foliar fertilization with nano-macronutrient fertilizer at concentrations led to an increase in the biomass and dry mass of the studied plants (Abobatta, 2023). As a result, the findings of this study confirm that aquaponics technology constitutes an efficient and sustainable agricultural system that contributes to water conservation and improves plant production efficiency. *S. podophyllum* has also demonstrated high adaptability and growth performance in closed aquatic systems, making it a promising candidate for modern agricultural strategies aimed at sustainable development and optimal resource utilization (Lauguico *et al*., 2024).

CONCLUSIONS

A study on *S. podophyllum* plants has shown that balanced NPK and nano-fertilization within aquaponic systems enhances plant growth and nutrient uptake efficiency. At the same time, high fertilizer concentrations can have adverse effects. This system contributes to sustainable and effective improvements in plant productivity and quality.

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CONFLICT OF INTEREST

All ethical guidelines regarding nanofertilizer preparation and treatment of *S. Podophyllum* Plants have been implemented within the limits of health safety and care issued by national and international organizations in this report.

استجابة نبات ***Syngonium podophyllum*** للأسمدة النانوية والكيميائية في نظام الزراعة الاحيومائية المستدام

جيهان يحيى الحاتم
قسم البستنة وهندسة الحدائق / كلية الزراعة والغابات / جامعة الموصل / الموصل / العراق

الخلاصة

في ظل الجهود المبذولة لدمج التقنيات المتقدمة في مجال الزراعة، ظهرت تقنية الأكوابونيك كحل متكامل لتطوير نظم الزراعة المستدامة، اذ تجمع بين تربية الأحياء المائية والزراعة بدون تربة، مما يوفر بيئة مثالية لنمو النباتات. وبناءا على ذلك، اجري البحث لغرض إكثار نبات *Syngonium podophyllum* باستخدام هذه التقنية، مع دراسة تأثير سماد NPK النانوي ومقارنته بسماد NPK التقليدي المعدني على نمو

واكثار هذا النبات. وقد بيّنت البيانات التجريبية بوضوح أن الرش الورقي بسماد NPK النانوي بتركيزي 1 و2 ملغم/لتر أدى إلى تحفيز واضح لمؤشرات نمو النبات الأساسية عند مستوى احتمال ($p<0.05$)، ولاسيما ارتفاع النباتات وقطر الساق وكذلك لوحظ زيادة طول أطول جذر ، فضلا عن زيادة تركيز النتروجين والبوتاسيوم للنباتات المعاملة بشكل ملحوظ مقارنةً بالأسمدة التقليدية المعدنية والتي تفوقت جميعها عن معاملة السيطرة، كذلك زاد تركيز الكلوروفيل والكاروتين والتي بلغت (22.664 و 102.86) ملغم غم$^{-1}$ على التوالي عند التسميد بسماد NPK النانوي بتركيز 1 ملغم لتر$^{-1}$، ويعزى ذلك الى الخصائص الفريدة للأسمدة النانوية مثل الكفاءة العالية في الامتصاص، والاطلاق البطيء للعناصر الغذائية، وتقليل الفاقد. هذه النتائج تفتح آفاقًا جديدة لتعزيز كفاءة نظم الأكوابونيك من خلال تطبيقات النانو تكنولوجي، مما يسهم في تحقيق إنتاجية أعلى وجودة أفضل للمحاصيل النباتية لأجل دعم تطور الزراعة الحديثة في العراق.

الكلمات المفتاحية: الزراعة الاحيومائية، سمادNPK النانوي، تقنية الغشاء المغذي، نبات السنكونيوم.

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